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A
L E C T U R E
O N
MUSCULAR MOTION,

READ AT THE
ROYAL SOCIETY,

THE 13TH AND 20TH OF NOVEMBER, 1788.

BY
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LONDON: PRINTED BY JOSEPH COOPER;
AND SOLD BY J. MURRAY, N^o. 32, FLEET STREET; J. JOHNSON,
N^o. 71, ST. PAUL'S CHURCH YARD; AND J. STOCKDALE, OPPOSITE
BURLINGTON HOUSE, PICCADILLY.

ledge which, being considered as belonging to particular professions, appear less interesting to men who entertain a taste for general science; and this has in some measure been the case with inquiries relating to the animal œconomy. But when we consider the rank which animated beings hold in the scale of Nature, and that Muscular Motion involves some of the most important circumstances relating to them, it cannot be denied that this is a subject highly interesting, as a branch of natural knowledge in general, independent of its utility as subservient to medicine. For though sensitive beings bear no assignable proportion to the great volume of the material world, yet as man belongs to this class of existence, and as all other existence would seem to be created in vain, unless there were beings capable of perception and enjoyment, the investigation of animal nature appears to be of the utmost importance, not only as the grounds of a useful art, but as an object of philosophical curiosity.

Extensive influence of muscular power in the animal œconomy.

Muscular motion is justly deemed an important and a characteristic attribute of animated beings, not only as conferring that locomotive faculty peculiar to animals, and that power by which they are enabled to exercise a command over external objects, but also as it constitutes that energy by which the motion of the fluids and all the internal functions of the body are carried on. For we are to consider as muscles not only those large masses of flesh which compose so great a proportion of the whole bulk of the body, but likewise all the minuter organs subservient to circulation, nutrition, and secretion; since not only the heart itself, but the whole vascular system and the intestines, owe their action to certain powers of irritability and contractility peculiar to muscular fibres.

In investigating this subject, it seems most natural to begin by comparing the muscles, and the motion belonging to them, to other modifications of matter and motion that occur in nature.

A muscle, even in so far as its structure is an object of our senses in its dead state, has characters which distinguish it from every other substance in nature. The most striking of these, is its regular organization of parallel fibres. The fibrous structure is, indeed, found in other parts of the body, such as the tendons and ligaments, and also in vegetables, some of which are even possessed of visible irritability; and a similar conformation is manifest in some minerals, such as the *asbestos*; but there is a certain degree of tenacity, elasticity, and moisture, which, joined to its fibrous organization, distinguish it from every other form of matter. With regard to the minute structure of muscles, though some have fancied they have seen, by the help of glasses, the ultimate fibres, and these consisting either of hollow tubes, or strings of vesicles, or rhomboidal articulations, according to the respective theory with which the mind of the observer was prepossessed, it appears, from the best microscopical observations, that the fibres are divisible beyond what the powers of the best assisted sight can trace, and that they are to all appearance uniform.

Properties of a
Muscle in its
dead state.

This regular fibrous structure of muscles, may be compared to the crystallisation of salts, and other regular forms which inanimate bodies assume, when passing to a solid form from a state of solution or fusion. Every species of matter has a mode of aggregation peculiar to itself, when its particles are at liberty to attract each other according to that tendency which has been called their *polarity*. Those who first conceived this idea, seemed to have proceeded on

the supposition of the ultimate particles of matter being solid bodies, infinitely hard, having their different sides endowed with different powers of attraction and repulsion, so as to give various configurations to the parts of matter, when concreting into a solid form. There is another and later idea* of polarity, founded on the hypothesis of the ultimate particles of matter being combinations of attracting and repelling points, which when brought much within the natural limits of these powers, produce unequal degrees of attraction and repulsion at equal distances from their common centre, thereby defining what may be called the shape of the particles, and constituting polarity. In whatever manner we conceive this to take place, some such circumstance seems universal, and perhaps necessary to all the varieties of solid matter; and there is in some instances a difference in the appearance and other properties of the same substance, after passing from a fluid to a solid form, according as its particles have been at liberty to follow more or less freely the tendency of their polarity in the act of concretion. This may be illustrated by the freezing of water, and the crystallisation of salts, which are more or less regular or confused, according to the circumstances in which they have taken place. The same may be exemplified in metals and other substances; for it is well known, that the properties of iron and glass, in point of cohesion and elasticity, are very much affected by the quickness or slowness with which they pass from a state of fusion to a state of solidity. It is probably in some circumstance of this kind that muscles differ from other soft animal matter. We cannot trace by inspection the manner in which the fluid nutritious matter is *applied* in forming solid parts; but as muscles are composed of parts so regularly figured

* See Dr. Blagden's Experiments on the cooling of Water below its freezing point. Phil. Transf. Vol. LXXVIII. page 143.

and endowed with contractility, it seems probable that there is some provision made by Nature, whereby the particles follow the exact impulse of their polarity, and constitute a more exquisite structure than in other parts of the body.

So far with regard to the character of a Muscle, considered in its dead state.

The first circumstance that meets the attention in considering its living state, is that contractile power or motion, which is properly the subject of this Lecture; and in order to investigate its nature, it will be necessary to compare it with that which takes place in inanimate bodies, by considering the nature of motion in general.

Muscular Motion considered in relation to other motions.

So far as we know, either from actual observation, or from analogy, there does not exist in nature any such thing as absolute *rest*: for when we contemplate the motions of the earth and heavenly bodies, the various complications of the planetary revolutions in their rotation round their own axes, and in the paths of their orbits, in the irregularities arising from the disturbances of their mutual gravitation, and from the precession of the equinoxes, not to mention the influence of the innumerable sidereal systems upon each other *, it may be affirmed, on incontestible principles, that no particle of matter ever was, or will be, for two instants of time, in the same place, and that no particle of it ever has returned, or will return, to any one point of absolute space which it has ever formerly occupied. Whether motion, therefore, can strictly be called an *essential* property of matter or not, it is, certainly, by the actual constitution of nature, originally and indefeasibly impressed upon it; and as rest does not

Motion an original and natural property of all matter.

* See Dr. Herschel's paper on the construction of the Heavens. Phil. Transf. Vol. LXXV. page 231.

exist in nature, but may be considered, in a vulgar sense, as a fallacy of the senses, and in a philosophical sense, as an abstraction of the mind, it follows, that what is called the *vis inertiae* of matter, is not a resistance to a change from rest to motion, or from motion to rest, but a resistance to acceleration or retardation, or to change of direction. If it should be alledged, that any given particle or portion of matter is carried along by virtue of the motion of the planet to which it belongs, it may be answered, that the earth or any other planet is nothing more than a congeries of such particles, each of which must possess a share of the same energy which animates the whole mass.

Farther proof
of the active
nature of mat-
ter.

Mechanical
impulse cannot
be a primary
cause of mo-
tion.

The active nature of matter is farther proved by those attractions and repulsions which universally take place among its parts, however near or remote ; and every instance of motion within the cognifance of our senses, in the bodies around us, is referrible, either in itself or its cause, to some mode of attraction or repulsion. Mechanical impulse being the most familiar cause of motion in the ordinary events of life, is apt to be considered as the most simple and original cause of it ; but it is obvious, upon reflection, that it cannot originate in itself, and that all collisions are produced either by the efficiency of living animals, that is, by muscular action, or by means of some operation of nature, depending on attraction or repulsion. Of the first kind, all the mechanical operations of art are examples ; and with regard to the others, they may, if carefully investigated, be referred in every instance, either immediately or remotely, to the above-mentioned inherent energies of matter. The natural agitation of air or water, for instance, may produce motion by impulse, or may bring two solid bodies to impinge upon each other ; but it is evident that these motions in the atmosphere

or the ocean, could not take place without gravitation, which is one of the attractive powers of matter.

Attraction and repulsion may be considered as one principle, inasmuch as they are both expressive of that active state originally inherent in matter, and because any two particles, having affinity with each other, either attract or repel, according to their distance, their common temperature, and other circumstances; and it is so universal an agent in nature, that some modern philosophers have made it absorb, as it were, every other power and property of matter. The late Father Boscovich*, of Milan, about forty years ago, advanced a very bold doctrine to this effect, alledging, with great strength of argument, illustrated by geometrical reasoning, that there does not exist in nature any such thing as impenetrable extended particles; and he deduces all the phænomena of the material world from one principle, which supposes it constituted of points having several spheres of attraction and repulsion, which being variously arranged and combined, produce the different forms and properties of matter, and its several powers, such as chemical attraction, cohesion, and gravitation. Whether this hypothesis is founded in truth or not, it would appear from the reasonings made use of, that all the relative properties of matter may be accounted for, though we abstract from every other consideration but attraction and repulsion.

Hypothesis of attraction and repulsion constituting the essence of matter.

It is evident, therefore, that whatever may be the cause of muscular motion, it is not referrible to mechanism, which is itself only

Muscular motion cannot depend on any mechanical cause;

* See this doctrine fully explained, in a work entitled, *Theoria nova Philosophiæ naturalis redacta ad unicam legem, &c. Auctore Rogerio Boscovich. Venetiis, 1763.*

a secondary principle. Some theories have had recourse to the conveyance of a fluid into the fibres of muscles, by which they were swelled, and thereby shortened. One of the most plausible of these hypotheses supposes this fluid to be the blood; but this is plainly a *petitio principii*; for, in order to give motion to the blood, the very power in question is necessary. Other fluids have been supposed to have this effect, but even the existence of these has not been proved. I will not detain this learned audience with a recital of the numerous theories of this kind that have been invented by fanciful and ingenious men, only *one* of which can be true, and the most solid objections could be urged against them all. Other arguments, derived from the nature of irritability and sensibility, could, if necessary, be brought to prove that Muscular Motion cannot depend on any mechanical cause: but this part of the subject was fully treated of by the ingenious Gentleman who delivered the Croonian Lecture last year.

But an original law of Nature.

As it has been proved that all matter is in a state of perpetual motion, originally impressed upon it by Nature, also that attraction and repulsion are essential to it, and the ultimate causes of all new motions that can arise in the universe, mechanical action being only a secondary cause, it seems most agreeable to the analogy of nature, to refer Muscular Motion to an original law of animated matter, whereby its particles are endowed with an attractive power for which no cause can be assigned, any more than for gravitation, cohesion, or chemical affinity. If I understand it right, this was the doctrine laid down and illustrated last year by Doctor Fordyce, and to which I am endeavouring to contribute some additional proofs and illustrations, from a conviction that it is the only rational and philosophical light in which this subject has hitherto been viewed.

If

If the shortening of a muscular fibre depends on this increased power of attraction between its particles, the effect of it will be to add to the power of cohesion in the fibre, and if this shall be found in fact to be the case, it will be a farther proof of the doctrine just now advanced. In order to decide this, I made the following experiment upon the flexor muscle of the thumb of a man, five hours after death, while the parts were yet warm and flexible. All the parts of the joint having been separated, except the tendon, a weight was hung to it, so as to act in the natural direction, and was increased gradually till the muscle broke, which happened when twenty-six pounds had been appended. I found that a man of the same age, and the same apparent size and strength, with the subject of the preceding experiment, could with ease lift thirty-eight pounds by the voluntary exertion of the same muscle. It is farther in proof of this fact, that in the case of a violent strain from muscular contraction in the living body, it is the tendon that gives way, whereas we have seen, in the experiment just now related, that in the dead body, the muscle is the weaker of the two. It is also well known, that in cases of over-exertion, the muscular fibres themselves do not give way, though the strongest tendons, such as the *tendo Achillis*, and even bones, such as the knee-pan, are broke by their living force *, which, in such instances, must be many times greater than the strength of the dead fibres.

A proof of this from the increased power of cohesion.

Experiment.

* There is a case related in the Philosophical Transactions, by Mr. Amyand, wherein the *os humeri* was broken by an exertion of the muscles. See Phil. Transf. Vol. XLIII. page 252. Every one has observed or heard of fractures happening from very slight accidents. These occur most probably from a jerk of the muscles concurring with the external violence.

Proof from
the increased
hardness.

The sensible increase of hardness in a muscle, when in a state of contraction, may also be considered as a proof of an increased attraction of its particles to each other at that time.

Whether muscular contraction produces a change of density.

In investigating this subject farther, it is of importance to determine, whether or not a muscle, when in a state of contraction, undergoes any change of density. A comparison of it in this respect with dead matter, may throw some light on the nature of muscular action.

Every homogeneous body possesses a certain degree of density, determined by the distance of its integrant particles. The most common means in nature, by which the density of such bodies is altered, are heat and cold; the one universally producing expansion, the other condensation. Whether mechanical force has the same effects is a point in natural philosophy not so well ascertained; for though tension and collision produce in solid elastic bodies a change of figure, which they immediately resume when the force is withdrawn, it has not been enquired, so far as I know, whether in such cases, a change of density takes place while the body is in the state of elongation or compression. Two elastic balls, in the act of collision, undergo a momentary change of figure, so that there must be an approximation of particles in the direction in which they are flattened; and in the elongation of an elastic chord by tension, there must be an increased distance of the particles in one direction, but while these changes take place in one dimension of the respective bodies, they may be compensated by contrary changes in the other dimensions; so that the several bodies may preserve, upon the whole, the same solid contents. In order to ascertain this in the
case

case of tension, which is the only case bearing analogy to Muscular Motion, I made the following experiment : I took a piece of the elastic gum, or *kaboutchouck*, three inches square, and about the eighth of an inch in thickness ; I procured a piece of sheet-tin, three inches broad, and six inches long, cut into sharp teeth at each end. The gum was first weighed in air, and found to be 380.25 grains. It was then weighed in water, along with the tin, to which it was loosely attached, and the weight of both was then 758.75 grains. The gum was then stretched upon the tin, by means of the teeth at each end, to a surface of about five inches square, the tin being bent so as to leave a free space between it and the gum, in order that when immersed in the water, no air bubbles might be entangled. In this situation, the weight of both in water was found to be 746.75 grains. Here was a difference of twelve grains, which could be owing only to a diminution of specific gravity ; and in order to be sure that there was no fallacy nor inaccuracy in the experiment, the gum was immediately afterwards disengaged from one end of the tin, so as to allow it to shrink, and being again weighed in this state in the water, it was found to have recovered exactly its former weight. This, as well as the subsequent statical experiments, was performed by means of the exquisite balance lately invented and constructed by Mr. Ramsden, and belonging to Sir Joseph Banks, who politely allowed me the use of it. I was also assisted by Mr. Gilpin, clerk of this society, who is extremely accurate and expert in all operations of this kind.

Now, does the state of relaxation and contraction make in like manner a temporary difference in the density of muscles ? When the circumstance of *decurtation* only is considered, we should be tempted to think that there must be an approximation of the particles of the

Experiments to determine whether the density of a Muscle is affected by contraction.

fibre ; but there is at the same time a lateral swelling of the muscle, which may compensate for what is lost in the other dimension. This point cannot be decided but by an experimental examination. It might be determined whether a muscle occupies most space when relaxed or when contracted, by finding its specific gravity in each of these states by means of the hydrostatical balance. But this would be found extremely difficult ; for the state of contraction is very transitory, and the motion itself would produce such a disturbance, as would render the result unsatisfactory. As there is this obstacle to the experiment on a living muscle, it occurred to me that it might be performed on the muscles of a fish, which had undergone the operation of *crimping*, as it is called ; for, in consequence of dividing the muscles, by cutting them when alive, they undergo a contraction, which continues after death * ; and upon comparing, by the hydrostatic balance, portions of muscle which had been crimped, with those of the opposite side of the same fish, which had on purpose been saved from this operation, it did not appear that there was any difference in the specific gravity. Two

* It has been made a question, whether life and its actions may not affect the *absolute* gravity of bodies ? Though this doubt has not arisen upon any assignable grounds that I know of, unless it be that one unknown principle may affect another equally unknown, I thought it might be worth while to determine it by experiment. The first trials were with animals of warm blood inclosed in oilskin, and close tin vessels, but not being satisfied with the accuracy of these, from the difficulty of cutting off all communication with the external air, so as to prevent moisture from exhaling, I inclosed live eels in flasks, and sealed them hermetically ; and, in this situation, their weight when alive being compared with their weight when dead, there did not appear any reason to suspect that the mere circumstance of life made any difference in regard to gravity.

trials

trials were made, one with the maffeter muscles of a skate, the other with the fides of a large trout.

The following experiment was also made, in order to decide the comparative density of a contracted and relaxed muscle. I took a glafs flask, into which one half of a living eel was introduced. The mouth was immediately afterwards fufed by a blow-pipe, and drawn into a tube like the ftem of a thermometer. The flask and tube were then filled with water, in order to fee whether the motion of the animal would make the fluid rife or fall. It had neither the one effect nor the other, though there were at times ftrong convulfions, and if the muscles had at any one time occupied either more fpace or lefs than at another, a fenfible fluctuation would have been produced, efpecially when the column of fluid was rendered very fine, by the introduction of a fteel wire to irritate the parts. That part of the eel from the *anus* to the tail was made ufe of for this experiment, as the other divifion, containing the organs of refpiration and the air-bladder, might have occafioned a fallacy, from the expanfion or condenfation of an elastic fluid, by accidental changes of temperature, or compreffion. This was repeated three times, with the fame refult. In one of the trials, the above-mentioned portion of two eels was introduced, and though they were at times both in convulfions at once, not the leaft motion of the fluid in the tube could be perceived.

I was the more defirous to be accurate in this and the preceding experiments, as the refult of them was different from my own pre-
poffeffion at the time, and different, I believe, from the opinion of
moft modern phyfiologifts. It may fafely be inferred from them,
that the contraction of a muscle produces no change in its density,

Contraction
produces no
change of den-
fity;

and

and that animal life differs from inanimate matter in this respect, as well as in most of its other properties and laws. One purpose in nature for muscles always preserving the same density may be, that as some of them act in confined cavities, inconvenience might arise from their occupying more space at one time than another. In the extremities of crustaceous animals, for instance, which are filled with muscles, a change of density would be apt to burst them. This may also be considered as a proof of the fact itself.

Nor of temperature.

Another circumstance in which the contractions of muscles differs from simple elasticity is, that the former, however frequent and violent, does not produce any heat as collision and tension are known to do. This may admit of some cavil with regard to animals of warm blood; for, one of the theories with regard to animal heat is, that it arises from the perpetual vibration of muscular fibres, particularly those of the vascular system; but this will not hold with respect to animals of cold blood, in which the actions of life are equally vigorous.

Recapitulation and comparison of facts.

The principal phenomena, therefore, of Muscular Motion, are the shortening of the fibres, the lateral swell, the increase of cohesion and hardness, and the unchanged density and temperature. It would appear, from the two last circumstances, that the intimate motions of the particles in relation to each other, must be different from what take place in the several instances of contraction and expansion in dead bodies. In the expansion arising from the action of heat, and the contraction from cold, the change of density shews that in the one case, the ultimate particles must recede from each other; and in the other case, that they must approach. The same may be said of elasticity. But as there is no alteration of the density

sity of a muscle in passing from relaxation to contraction, this change cannot consist in the approximation of the integrant parts of the fibres, but must depend on some other circumstance in the intimate disposition of the particles. In attempting to conceive in what this consists, the following explanation may be offered:—

It was formerly mentioned that the regular structure of solid bodies depended on the polarity and shape of their integrant parts. Now all bodies, except such as are sphaerical, must have a long and a short axis ; and let us imagine the fibres of muscles to be composed of sphaeroidal particles ; we may then conceive relaxation to consist in their being disposed with their long axis in the line of the fibres, and contraction to consist in their short axis being disposed more or less in that direction. This will not only account for the decurtation, and uniform density, but for the lateral swell, and also for the increased hardness and cohesion ; for though the particles do not approach or recede, as in bodies simply elastic, yet their power of attraction will be increased by their centres being brought nearer, and by being applied* to each other by more oblate surfaces. This hypothesis accords with what has been before proved, concerning the unchangeable density ; for what is lost in one dimension, is gained in another ; and the cause for there being no increase of temperature, depends probably on the same circumstance by which the density is preserved unaltered.

A Theory of
Muscular contraction.

* By being applied, I do not mean that they are actually in contact ; for it is evident, from the effect of heat in expanding bodies, and of cold in condensing them, that there can be no such thing as contact of the ultimate particles of matter, even on the supposition that these consist of impenetrable bodies infinitely hard.

This account
of Muscular
Motion does
not account for
the operation
of *stimuli*.

WHAT has been hitherto advanced on this subject, has tended only to explain that state of a muscular fibre which renders it susceptible of contraction, and to ascertain the nature of that change which takes place in passing from the state of relaxation to that of contraction. It still remains a question by what efficient power this contraction is excited. We have, indeed, referred the cause to attraction; but of attractions some are perpetual, such as gravitation, which exerts an equal and unremitting *nifus* upon every particle of matter, which is the subject of its action; and there are others fugitive and occasional, such as electricity and magnetism, and we may add muscular contraction. With regard to the first kind, as it is always uniform, it seems sufficient to say, that it exists as a part of the invariable constitution of nature; but with regard to that which is fluctuating, it seems incumbent on those who search into the laws of nature, to say by what mode of efficiency the attraction is performed, so that its action should take place at one time, and not at another. In order to answer this question, with regard to Muscular Motion, we ought to be able to specify by what mode of operation a *stimulus* excites contraction. Those theories which account for the contraction of muscles, by the swelling of the fibres, in consequence of a conveyance of matter, professed to account for the operation of *stimuli*; but upon the principles I have adopted in this Lecture, I am obliged to confess my entire ignorance on this subject. Perhaps it is inscrutable. Perhaps the state of human knowledge is not ripe for such an inquiry; for we are still in the dark with regard to most of those properties of matter which bear any analogy to this, and the knowledge of which might tend to throw light upon it. We know that electric attraction depends on the accumulation of a subtle fluid,

fluid, but we are ignorant of the nature of magnetism. With regard to heat, which is universally a cause of repulsion, and the most general, powerful, and active, as well as the most useful and familiar agent in nature, it is hardly decided as yet whether it is a matter or a quality; and with regard to light, though it is itself the medium by which we become acquainted with the most remote objects, it is so obscure in its own nature, that it is still a question whether it consists in the transmission or vibration of a subtle fluid.

As I am unable, therefore, to explain the *operation* of *stimuli*, I shall content myself with endeavouring to *enumerate* them.

Every natural cause exciting the contraction of a muscular fibre, is called a *stimulus*. They may be divided into internal and external. As an example of the former, the circulation of the blood may be mentioned; as this is kept up by an exciting influence of the blood upon the heart and vessels which contain and impel it. The earliest perceivable instance of Muscular motion, is the beating of the heart, as it is seen in the first rudiments of the embryo in an egg, and called the *punctum saliens*. There seems to be established by nature, a certain *habitude* of action between the vessels and their fluids, whereby the former are duly stimulated to propel the latter. This does not depend merely on the acrimony of the fluids; for if a fluid even more mild than the blood, such as milk, be injected into the circulation, it will produce great disturbance; and if the blood, by being deprived of the influence of respirable air, becomes destitute of a certain property which it would naturally acquire in the act of respiration, it does not prove a *stimulus* to the heart.

Enumeration
of Stimuli.

1. Internal stimuli.

All the functions of the body are carried on by specific *stimuli*.

The irritability of all the containing parts, is in like manner accommodated to the nature of their respective contents. The intestines are so calculated, as to have proper motions excited in them by the aliment, and the secretions which are mixed with it; and there are bodies which, though perfectly mild, such as alimentary substances of difficult digestion, yet excite more violent commotions in the stomach than other substances which are very acrimonious. The various effects of poisons in different parts of the body, may also be mentioned as an illustration of the peculiar susceptibility of the several organs of the body. The poison of a viper, for instance, is perfectly innocent, not only in the receptacles of the animal which produces it, but it may be taken into the stomach of any animal without the least bad effect, and only exerts its deleterious power when brought in contact with a wounded part. Some vegetable poisons, on the contrary, such as that of laurel water*, prove deadly, when taken into the mouth, or applied to any part of the alimentary canal, but are innocent when injected into the veins. The same principle might be illustrated by the operation of various medicines, some of which act upon one set of organs, and some upon another. But it is meant here more particularly to elucidate the natural internal actions of the body; and it may be remarked, that the receptacles of the several secreted fluids, such as the gall bladder, and bladder of urine, are so adapted to their natural contents, by a due measure of irritability, as to bear their accumulation to a certain degree, and then to expel them. We have here also a proof that irritability is not in proportion to sensibility; for both these receptacles are extremely sensible to pain and irritation, from extraneous acrimony, though so moderately sensible to the acrimony of their natural contents. This disposition in the several organs to

* See Experiments on Poisons, by Abbé Fontana.

perform their natural functions, in consequence of the *stimulus* of the respective fluids they contain, has aptly enough been called the natural *perception* of these organs *.

It follows from this, that the application of chemical and mechanical *stimuli* to irritable parts, is not a mode of experiment likely to be productive of useful knowledge, since the internal organs are calculated to perform their actions in consequence of peculiar and specific *stimuli*, provided by nature; and this consideration may serve to suggest the most likely means of restoring lost irritability and action to the vital functions, when suspended by suffocation, strangulation, or submersion. The action of the heart depends on the action of the lungs and the inspiration of atmospheric air; and I have found, from repeated experiments on animals, that in such cases, all other means of restoring circulation and life, are of little or no avail, in comparison of inflating the lungs with atmospheric air, and by stroking and pressing the ribs, so as to imitate the action of respiration. Neither mechanical friction, nor any other external *stimulus*, nor stimulating clysters, seemed to have any sensible effect in recalling life. The only other means, besides those above mentioned, that seem material in attempting to restore suspended animation, is a due attention to the external temperature. In the case of drowning in cold water, for instance, it is of the utmost consequence to restore the natural warmth, either by the cautious use of artificial heat, or the application of living bodies. In the case of those who have been suffocated by foul air, it is, on the contrary, adviseable to expose them to cool air.

Application of this in suggesting the means of restoring life in case of strangulation, &c.

* This idea is well illustrated by Mr. Hunter in his lectures; also by Mr. Mudge, in a dissertation on the *vis vitæ*, subjoined to a tract, entitled, "A radical and expeditious cure for a catarrhus cough."

And to pathology.

From what has been before advanced, concerning that habitude or mutual influence of the solids and fluids, it would appear that they are specifically appropriated to each other, in order to carry on not only the circulation, but the important functions of digestion, absorption, secretion, and excretion; and as the healthy condition of an animal consists in the maintenance of that natural harmony, so must the state of disease depend on the derangement of those delicate impressions and nice sensibilities, or rather *irritabilities*, in which the functions of the several organs consist; and as the affections of the solids and fluids are reciprocal, disease may depend either on some deviation of the former, from their healthy and natural perceptions, or from some acrimony or vitiation of the latter, or perhaps more commonly from the concurrence of both, in consequence of their mutual influence. When the fluids only are morbidly affected, nature alone is possessed of resources of cure; for if the containing solids retain their natural irritability, they will be stimulated to expel what is extraneous or vitiated. A depraved state of the solids is therefore likely to prove a more frequent cause of morbid derangement; and as they differ from the fluids, by possessing an inherent activity, it is the object of medicine to incite, restrain, or alter their diseased actions, according to the nature of the morbid affection.

It is evident, that this doctrine will admit of a much more extensive application in pathology, than there is time here to follow out; and I shall confine myself to the illustration of it, in the case of the absorbent vessels. These evidently possess a power of absorbing certain substances, and rejecting others. The lacteals, for instance, in a state of health, take up
only

Exemplified
in the absorbents.

only the nutritious part of the alimentary mass ; for there is in the fecal part substances equally soluble as the chyle. The inner surface of the gall bladder is beset with absorbents, which, however, do not absorb bile in the ordinary state of health, and only concentrate it by taking up the fluid with which it is diluted. But when in consequence of the obstruction of the gall ducts, the bladder becomes over distended, or when the specific perception of the absorbents is depraved by disease, in these cases the bile is absorbed and thrown into the circulation. Sometimes, such unusual actions of the absorbents are excited as a resource of nature, either to cure disease, or to carry on growth ; for it has been shewn by Mr. Hunter, that not only soft and fluid parts, but bone, can be removed by absorption. At other times, disease consists in affections of these vessels, either by their action being too much retarded, as in the case of dropsy, or where the matter of an ulcer, or in the pustules of the small pox, is prematurely absorbed, in consequence of the depraved action of fever. It is sufficiently demonstrable, that the whole surface of the skin and *bronchiæ* is beset with inhaling vessels, which absorb the fluids dissolved in the atmosphere ; and it would be contrary to the analogy of the rest of the body, to suppose that these are not possessed of some elective power, whereby they prefer or reject such fluids as are presented to them, according to their several qualities, and that this power should not be various, according to the state of health or disease. But, independent of analogy, the variable state of the human body, in respect to its susceptibility of contagious diseases, seems to be a direct proof of this. It is a well-known fact, that a person who has never had the small pox, will at one time be closely exposed to their infection, and yet

yet escape the disease, and at another time will be affected by the slightest degree of it. If it should be said, that the poison is inhaled in the one case as well as the other, but that the internal state of the body is in one case disposed to be affected, and in the other not, it may be answered, that any method by which it can certainly be introduced, as by inoculation, will almost infallibly produce this disease in constitutions that have never before undergone it. And this seems to afford a solution of a much agitated question, On what does the superior safety of the inoculated small pox depend? For, in a constitution already morbidly disposed, the powers of life will be more apt to give way to any disturbance that may be excited; and the same derangement of nature, which, in this case, makes the inhalant vessels admit the noxious effluvia of disease, will render the body less capable of counteracting it when admitted. In the case of inoculation, the poison is not taken into the circulation by any natural operation of the body; but being obtruded by art, there is no particular propensity in the constitution to give way to it, unless the time of inoculation should accidentally coincide with those moments in which the body is naturally susceptible; and as this must sometimes happen, it is accordingly observed, that one case in a great number of inoculated small pox, is equally malignant as any case of the natural sort.

The superior safety of inoculation accounted for.

Analogy between motion and sensation.

The specific irritability of muscular fibres, in consequence of the peculiar action of *stimuli*, has been called *perception*, as was mentioned before. This term is not to be taken in a sense strictly literal, but as a metaphor, borrowed from sensation, and applied to motion. In like manner as the senses are fitted to convey peculiar ideas, in consequence of their respective organs being adapted to their corresponding external impressions, so are the various organs of

of motion by nature made susceptible of excitement from peculiar impressions, either internal or external. This analogy is the more exact, that the nerves seem to be the instruments of both; for not only the organs of sensation and voluntary motion, but those of involuntary motion, are supplied with nerves, and dependant upon them; for if the influence of the nerves leading to the heart or intestines is interrupted, by cutting ligature or palsy, the function of these parts is thereby destroyed. Thus, as there is a peculiar sensibility belonging to the several senses, so is there a peculiar irritability belonging to the several organs of motion. The intention of Nature, therefore, in distributing nerves to every muscular organ, was probably in order to constitute those peculiar perceptions on which the various vital and natural functions depend. But I give this only as a conjecture; and though the nervous influence may thus *modify* irritability, there is reason to think that it does not *bestow* it.

This leads us to consider how far vitality is dependant on the nerves. It has been the opinion of some physiologists, who have been supposed to entertain very rational ideas of the animal œconomy, that all muscular irritability depended on a sentient principle*; and some have even maintained, that there is an intelligent principle† residing in animal bodies, in order to guide their functions and operations. From the preceding facts and reasoning, and from its being well attested that there have been several instances of the production of foetuses, without the brain‡, there seems

Whether vitality is dependant on the nervous system

* See Whytt on the vital and involuntary motions.

† *Vide Opera Stablii & Praelectio de anima medica, Auct. Doct. Nicholls.*

‡ See Phil. Transf. Vol. XIX. and XXI.

no occasion to have recourse to so violent a hypothesis. This, however, is not the question here intended to be discussed ; but it is meant to enquire, whether or not there is a foundation in nature for an opinion broached by Mr. Hunter, that there is a living principle, distinct from the nervous system, and independent of sensation and consciousness. The principal fact in support of this opinion, is the existence of animals without brain and nerves. That there are such, was, I believe, first observed by Haller*, and has been confirmed by Mr. Hunter ; who maintains farther, that the stomach is a centre, or seat of life, more essential to it than the brain. That the stomach should be an organ of so much consequence, seems natural enough, from the importance of its function, which is that of assimilation ; and life can be more immediately and completely extinguished by an injury to it, such as a blow, than by the same violence to any other part of the body. It is also well known, that the muscular fibres of animals, endowed with a nervous system, will retain their irritability for some time after their separation from the brain and nerves. It is evident, likewise, from the *phænomena* of vegetation, that irritability may exist in nature, without sensation, consciousness, or any suspicion of the existence of a nervous system. The facts I allude to, are not only the perceptible motions of the sensitive plant, but more particularly those motions which must necessarily take place in all plants, in carrying on their growth ; for there is no accounting for the accretion of solid parts, in consequence of the conveyance of nutrition by the propulsion of the sap, but by admitting some power, acting by laws different from those of dead matter. In favour of this opinion, it is farther observable, that those animals which are destitute

* *Vide Primas Lineas Physiologiæ*, cccclii.

of brain and nerves, are of the class *vermes*, the most simple in nature, having only one function, to wit, that of *assimilation*, and therefore not requiring that variety of action, and those peculiar perceptions which are necessary to more complex animals. Lastly, the state of an egg before incubation, and the condition of these animals which become torpid from cold, and afterwards revive, afford facts which favour this opinion; as they shew that there is a certain principle of self-preservation, independent not only of the operation of the nervous system, but even of the circulation; for, in this quiescent state, these portions of animal matter are preserved for a great length of time from that corruption to which they would otherwise be liable, and their fluids are prevented from freezing in a degree of cold, which would congeal them, were they destitute of every principle of life.

But though simple life may be considered as distinct from the nervous system, which is only an accessory appendage to it, yet in those animals in which they are conjoined, the purposes of nature render them dependant on each other. The functions of the brain, for instance, cannot go on without the action of the heart; for whenever the circulation of the blood is interrupted, consciousness and sensation are destroyed, as is evident in the case of a swoon, and in the effects of strangulation. On the other hand, as has been before observed, the action of the heart has a dependance on the influence of the nerves, as connected with the brain. There are also incontestible proofs of the extreme vessels being affected by the influence of the brain; for we know that a thought in the mind will produce partial determinations of the circulating fluids, as in the case of blushing, and the fullness of the vessels in the organs of generation, in consequence of certain passions. It does not,

The mutual dependance of simple life and nervous influence.

however, follow, from all this, that irritability depends on the nerves; the influence of which may be considered as modifying general irritability, in the manner already mentioned; or it may be considered rather as a *stimulus* to the muscular fibres, than as endowing them with irritability, as in the instances last adduced: and though the organs essential to life, such as the heart, cannot exert the action necessary to life, without the influence of the nerves, yet the vessels of the extremities can exert their usual action independent of it; for there are cases in which the natural heat and circulation continue in the limbs, after a total deprivation both of voluntary motion and sensation *.

Essential properties of simple life.

It may here be observed, that beside muscular irritability, the principal, if not the only, powers of simple life, are the assimilation of aliment, and that power in the living body, by which it preserves itself from putrefaction; and it is strongly in proof of vitality being independent of nervous power, that when the trunk of a nerve is cut through, the limb to which it leads, though deprived of all sensation and voluntary motion, not only continues free from sponta-

* This fact is ascertained, both by the experiment of cutting the crural nerve of a living animal, and by the circumstances attending certain diseases. I lately met with two cases of palsy, in which there was a total loss both of sensation and voluntary motion in the lower extremities, and yet the natural warmth and circulation remained. In one of these cases, excoriations were produced on the feet by sinapisms; and in the other, blisters rose on the knees, but without exciting any sensation, and the parts healed as in a healthy person. The first, was that of a gentleman advanced in life, in whom this affection came on after the gout in the stomach, and he died in consequence of the palsy extending to the bladder and other *viscera*. The other was that of a young woman in St. Thomas's Hospital, who had been subject to violent hysterical convulsions. After a tedious illness, she entirely recovered the use and feeling of her limbs.

neous putrefaction, but the warmth and circulation continue, even though the nerve should not be regenerated *. The only visible change produced in a limb by this operation, is, that after some time it begins to waste.

But there are circumstances that would seem to prove, that the nervous system is not only a mere appendage to life, but that it tends to impede its operation, and shorten its existence. Simple life will not only survive sensation, but will survive it longer, if the animal is killed, by destroying the nervous system, than if it had been destroyed by hæmorrhage, suffocation, or other violence. It is a curious and well ascertained fact, that if a fish, immediately upon being taken out of the water, is stunned by a violent blow on the head, or by having the head crushed, the irritability and sweetness of the muscles will be preserved much longer, than if it had been allowed to die with the organs of sense entire. This is so well known to fishermen, that they put it in practice, in order to make them longer susceptible of the operation called *crimping*. A salmon is one of the fish least tenacious of life, inasmuch, that it will lose all signs of life in less than half an hour after it is taken out of the water, if suffered to die without any farther injury; but if, immediately after being caught, it receives a violent blow on the head, the muscles will shew visible irritability for more than twelve hours afterwards.

The influence of the nervous system unfriendly to simple life.

This illustrated by observations on fish,

There is a circumstance observed with regard to animals of warm blood, which seems to depend on the same principle. An excessive exertion of voluntary motion, immediately before death, prevents the muscles from becoming rigid when cold, and renders them

On quadrupeds,

* It appears, from some experiments of Mr. Cruikshank, that there is a process in nature, whereby nerves can be regenerated after being cut through.

more prone to putrefaction. Thus, if an ox is killed immediately after being overdrove, the carcase will not become stiff when it grows cold, nor is it capable of being preserved by means of salt.

And diseases
of the human
species.

In illustration of the same principle, it may be remarked, that there is a symptom in certain diseases of the human species, shewing that digestion, which is one of the principal functions of simple life, will sometimes go on better, in consequence of lesions of the brain; for in those disorders in which the exercise of the senses is in a great measure destroyed, or suspended, as in the hydrocephalus and apoplectic palsy, it happens not uncommonly that the appetite and digestion are better than in health.

Every exercise
of the brain
produces fa-
tigue.

From these facts we may infer, with Mr. Hunter, that the exercise of sensation is inimical to life, and that a sort of fatigue is induced by this, as well as by voluntary motion: so that all that intercourse carried on through the nerves, whether *towards* the brain, in the case of sensation, or *from* the brain, in acts of volition, tends to wear out the animal powers*. And as intense and long-continued thought, though not terminating in any outward action, tends also to produce an inability for farther exertions, it would appear that the brain, or sensorium, is more particularly the organ which is subject to that species of sufferance called fatigue. From these facts, we perceive the necessity of sleep, which consists in a

Hence the ne-
cessity of sleep,

* There are some ingenious remarks on the analogy of sensation and motion, in a paper on the ocular *spectra* of light and colours, by Dr. Robert Waring Darwin, Phil. Trans. Vol. LXXVI. This dissertation abounds with refined and well-deduced observations on the subject he treats of.

temporary suspension of sensation, volition, and thought, and is a resource of nature, whereby the powers of life recover themselves after satiety and fatigue, which are provided as guards to warn us when nature is in danger of being strained, either by repletion or over exertion; and it is evident that such barriers were absolutely necessary, in order to set bounds to operations which are only occasionally requisite, and which would otherwise depend on the caprices of the will. The exercise of sensation and voluntary motion, in a moderate degree, is conformable to the intention of nature, and therefore salutary; and it is only when they are excessive, that they tend to wear out the powers of life, and more especially if these are not duly recruited by sleep. Immoderate labour, therefore, and watching, also spasms and convulsions of every kind, are unfriendly to health and long life: in like manner, sensations, when too frequent or intense, especially those which consist in the gratification of the senses, tend to wear out the animal powers; and hence we perceive why a life of sensuality is productive of certain diseases, independent either of the repletion or evacuation which attend them. The gout, but more certainly the palsy, seems to proceed merely from the indulgence of the senses; for the latter commonly enough occurs in the most spare and emaciated constitutions, and in those who have been accustomed to exhausting pleasures, as well as those of a full habit, who have indulged in the excesses of the table. A turgescence of the vessels in the brain will certainly be more apt to produce that rupture of them in which apoplectic palsy consists, when these vessels have been relaxed, as we conceive them to be, by frequent and intense sensations. But in those who are the reverse of being plethoric, and who fall victims to this disease, in consequence of too free indulgence in venereal pleasures, in the decline of life,

And the bad effect of immoderate labour and sensuality.

(as

(as every one who has much observation of the world, or experience in physic, knows to be a frequent case) it must arise from a preternatural weakness in the brain, induced by the mere circumstance of sensation. This accounts for what has been reckoned a difficulty in reasoning on the cause of apoplexy and palsy, to wit, that the same effect should be produced by those gratifications which produce repletion, as by those which produce evacuation.

And the good effects of removing irritation in certain diseases.

It follows, from the same principle, that when life is threatened by certain diseases, of which the chief symptom is irritation, any means by which sensation, whether natural or morbid, and muscular motion, whether voluntary or involuntary, convulsive or spasmodic, can be soothed or suspended, will prove salutary, by allowing the powers of life to rally, as it were, and recover themselves. In this consists the operation of narcotic medicines, such as opium, which, in complaints both of a general and local nature, proves useful not merely as a palliative, by the removal of temporary pain or spasm, or by procuring sleep, but as a principal instrument of recovery, by allowing the powers of life to exert their natural action, in consequence of the removal of irritation *.

* As an example of the general affections of the constitution in which opium is a useful remedy, we may mention those low fevers in which the principal symptoms are tremors, *pervigilum*, and low *delirium*. And as an instance of local affections, in which it has been found highly serviceable, we may mention ill-conditioned ulcers of all kinds, but particularly those which occur in the venereal disease. One of the principal difficulties in the cure of this disease, is that irritability of constitution whereby ulcers are so exasperated, by the use of mercury, as not to bear a sufficient quantity of it to produce a cure. This is obviated by a free use of opium, which seems more efficacious in such cases, than even Peruvian bark, or any other remedy; and this is one of the principal modern improvements in the treatment of this disease.

It

It is but just to own, that this is an idea which was first suggested to me by a learned and eminent physician* of this place, when in consultation with him a few years ago.

It would be curious, as well as useful, to distinguish the operation of medicines, as they affect simple or sensitive life. I attempted a comparison of this kind with opium, which, though it chiefly affects sensation, has also a powerful effect on simple life, as I found by trying its effects upon leeches, which are a species of animals without brain or nerves. In order to discern the power of this drug, as affecting the different principles of animals possessing both sorts of life, I took a solution of it in water, into one portion of which I put some sound living eels, and into another some eels, also alive, but having their heads bruised, choosing the former, as nearly as I could, of the same vigor with the latter, before their heads were bruised. It was found, in a number of trials, that the sound eels generally died sooner than the others. The opium had a double effect on the former, as it acted both upon the senses and upon the principle of simple life, and the effect upon the senses was more than equivalent to the external injury of the latter, upon which the opium acted only upon one principle, the senses being locked up by the destruction of their organs. In order to make this operation succeed, the solution should be of a certain degree of strength, so as to act as a poison. There should be at least half a grain of opium to an ounce of water. When the trial was made with a solution of half this strength, the sound eels lived much longer; for the time was then protracted to that period in which

Comparative
effects of opi-
um upon sen-
sitive and
simple life.

* Dr. Warren.

the wounded cels would have died merely of their injury. It may be mentioned, that those which had their heads bruised, and were put into a solution of opium, died considerably sooner than those which had suffered the same injury, and were put into plain water for a standard.

Stimuli connected with consciousness.

Having considered the various qualities of the fluids exciting the corresponding irritability of the respective vessels, as a leading principle in carrying on some of the most important functions of the body, and serving to account for many of the vital and involuntary motions, the only other internal *stimuli* that remain to be enumerated, are those connected with consciousness. The great masses of muscle in the trunk and extremities of the body, are the instruments of the mind in acting upon external bodies; and we may, therefore, reckon in the list of *stimuli*, the nervous power by which the will and the passions excite external motions. This is a function sufficiently important for the nerves, without admitting them as the principle upon which irritability depends. This question has been already discussed; but it may be farther observed, that the nervous power, being a stimulus acting upon an irritable principle in the muscular fibres, affords a presumption that they are different from each other; for, the matter being considered abstractedly, where any effect is the result of the concurrence of two bodies, as, for instance, in the combinations of chemistry, these two bodies must be different, in order to produce any given effect. It is otherwise, indeed, when the effect depends on mere *communication*, as in the case of mechanical impulse, where the same motion that is lost by one body is acquired by another. But it will not be said, that there is any similarity

larity between what takes place in a nerve, and what takes place in a muscular fibre in the act of voluntary contraction.

I have already acknowledged my ignorance of the manner in which *stimuli* in general operate, and that this must be admitted as an ultimate fact in nature. But the operation of the will through the nerves, seems involved in double obscurity; for as it depends on the nature of thought, it cannot be made a subject of experimental investigation. For this reason I shall decline the inquiry, as not being adapted to the ends of this Society; and it seems impossible for human sagacity to penetrate the connection of matter with sensation and volition, except by inferences more or less hypothetical. The properties of different bodies, in relation to each other, appear to be the only proper subjects of experimental reasoning; for, in their relation to the mind, they are only the effects, perhaps the remote effects, of their intimate nature upon the senses; so that we may venture to affirm that human reason can no more fathom the connection of thought with the corresponding changes in the corporeal organs, than the eye can see itself.

Those affections of the muscular fibres, which depend on the *passions*, though distinct from those excited by the will, may yet be enumerated here among those which flow from consciousness; for there are emotions of the mind that have visible and powerful effects on the heart and vascular system, which are organs entirely out of reach of the will. Not to mention the well-known effects of grief, fear, and joy, which affect the whole circulation, there are certain passions and sentiments which produce partial and local effects. These are established by Nature, either to answer some important natural purpose, as in the case of the congestion of the fluids in the parts of generation, in consequence of the venereal appetite,

Effects of the
passions on
muscular fibres

or to serve as natural expressions, as in the case of blushing and weeping. One of the most striking effects of the passions upon muscular action, is the influence they have upon the strength or mechanical force of the voluntary muscles. Fear produces debility, almost amounting to palsy. Courage and ardor of mind, on the contrary, adds to the natural strength. When the mind is agitated by some interesting object, and calls upon the body for some extraordinary exertion to effect its end, the muscles are thereby enabled, as it were by magic, to perform acts of strength, of which they would be entirely incapable in cold blood. In circumstances of danger, for instance, where life or honour are at stake, exertions are made in overcoming mechanical resistance, which seem incredible, and would be impossible, were not the mind in a sort of phrenzy, and it is truly admirable in the œconomy of nature, that an idea in the mind should thus in a moment augment the powers of motion, and inspire additional resources of strength, adequate to the occasional calls of life*. The great increase of strength in maniacs, is also referrible to the passions of the mind. These considerations would almost lead us to doubt whether or not the accounts we have of the great feats of strength ascribed to individuals in the heroic ages, are fabulous or not. It is also worthy of remark, that in

* This extraordinary degree of strength, infused into the muscles by ardent passions and affections, has been considered, by unenlightened minds and heated imaginations, as a *supernatural* influence; and the striking effects described above, may form some excuse for superstition in attributing them to the secret agency of some propitious and irresistible power. The etymology of *enthusiasm*, a word expressive of these uncommon exertions, shews that there was originally supposed to be, on certain occasions, some divine influence actuating the human frame. The consciousness of this increased vigor of mind and body, exalted by the belief of its divine source, will serve to account for those peculiar and astonishing efforts of enthusiasm, which are met with in the history of mankind.

great

great and lasting exertions of strength, to which men are impelled by active and generous affections, fatigue is not induced in the same proportion, by many degrees, as by the same quantity of muscular action in the cool and deliberate actions of common life*.

The other class of *stimuli* to be enumerated, are the external. 2. External Stimuli. These consist in impressions made by outward bodies. They are either immediate, as in the case of those motions which are excited by mechanical means, or by acrimony, directly and artificially applied to a muscular fibre; or they are remote, as in the various instances of sympathy, and in the case of those instincts which nature has constituted for the purpose of self-preservation in brutes, and in the early part of human life. I shall here confine myself to a few remarks on instinct, as the other branches of this subject have been fully and ably handled by those who have gone before me in this Lecture.

There is a connection established between the impression of certain external bodies and the action of certain muscles, analogous to what has already been noticed with regard to the internal motions excited in vessels by the peculiar *stimulus* of their fluids, Nature having instituted certain habitudes between outward *stimuli* and the moving powers whereby natural propensities are constituted, equally necessary to the support of life as the internal functions. Thus, in a new-born animal, the first contact of the external air excites the act of respiration, and the contact of the nipple excites the act of sucking; both of which actions are absolutely necessary to the

Analogy between internal and external stimuli.

* See Observations on the Diseases of Seamen. Book II. chap. III.

Instinct.

maintenance of life, and require the nice co-operation of a great number of muscles, prior to all experience. Actions of this kind are called instinctive, and differ from voluntary motions in this respect, that the latter are the result of memory and experience, whereas the former are the immediate effect of external impressions, in consequence of an established law of nature, and independent of consciousness. The actions of instinct and those of volition, nevertheless, run imperceptibly into each other, so that what was at first instinctive, may afterwards come to be a matter of deliberate choice. The same muscles are the instruments of both, and they differ from the muscles obeying the internal *stimuli*, such as the heart, in this respect, that they are liable to fatigue, and thereby concur with the exercise of sensation and of thought, in rendering sleep necessary. There are no muscles, except those of respiration, of which the constant action is necessary to life, and which are void of consciousness in their ordinary exercise, but which are yet in some measure under the control of the will. The principal end answered by this power of the will over the muscles of respiration in man, is to form and regulate the voice.

Certain instinctive actions, independent of sensation and consciousness.

But though instinctive motions are in some cases convertible into those which are voluntary, we should be so far from confounding them, that the former are even compatible with the want of consciousness and sensation; for those animals which are destitute of brain and nerves, are capable of actions evidently of the instinctive kind. A leech, for instance, being brought into contact with a living animal, is impelled, by an instinct of its nature, to fasten upon it, and suck its blood. There is something very similar to this even in vegetables, as in the case of tendrils and creeping plants

plants being stimulated, by the contact of other bodies, to cling round them in a particular direction. There are facts, which shew that instinctive actions, even in animals endowed with brain and nerves, do not depend on sensation. I took a live kitten, a few days old, and divided the spinal marrow, by cutting it across at the neck. The hind paws being then irritated by pricking them, and by touching them with a hot wire, the muscles belonging to the posterior extremities were thrown into contraction, so as to produce the motion of shrinking from the injury. The same effects were observed in another kitten, after the head was entirely separated from the body*. The like takes place with regard to insects; for, after the head of a bee is separated from the body, the hinder part will sting, upon the application of such a *stimulus* as would excite the same action in the animal in a perfect state. These facts shew clearly that instinctive motions may be exerted, without the intervention of the *sensorium commune*, and therefore without sensation or consciousness.

In what I have farther to say on this subject, I shall confine myself to the consideration of two of the most curious and important instincts, HABIT and IMITATION.

* In repeating this experiment, I found that when the spinal marrow was cut through, between the *lumbar vertebræ* and *os sacrum*, the posterior extremities lost their irritability, but the tail retained it. It might, therefore, be said, that the spinal marrow served as a sensorium; but it may be answered, that when the head is cut off, its irritability remains, as appears by the motion of the ears, when pricked or touched with a hot wire; and as the extremities are also irritable, it will not be said that consciousness and sensation exist in two separated portions of the body.

Habit, as applied to muscular motion.

It is the nature of a voluntary muscle to perform any motion with greater ease, the more frequently it is repeated, and to act most readily with those muscles, or in company with those sensations with which it has been used to combine its action, either at once or in succession. This is the foundation of habit, and though it is in common to man with other animals, it is the principle by which all his practical attainments acquire facility and perfection. It has been mentioned that some actions, originally instinctive, may afterwards be performed as acts of pure volition; so inversely, all actions, which are the result of reason and reflection, may be brought by habit to resemble instinctive actions, and thereby to be performed with greater expedition and effect.

Habit, as applied to sensation.

The term Habit has also been applied to sensation; for, as motions are more readily excited by frequent succession, so one perception excites the idea of another, in consequence of repeated connection. In this sense, it ought more properly to be called the association of ideas, a principle upon which Dr. Hartley has built a theory* of the human mind, perhaps the most just and consistent of any that has ever been framed. It is habit, taken in this sense also, which Mr. Hume† conceives to be the foundation of all our experimental reasoning, inasmuch as it constitutes the only original notices by which we acquire any intimation of the connection of cause and effect. But though this doctrine is ably and profoundly illustrated by that philosopher, it may be remarked, independently of other objections, that though habit may *give no-*

* This work has been re-published, with a preface, by Dr. Priestley.

† See Essays and Treatises on various subjects, Vol. III. by David Hume, Esq.

tice of this connection, it cannot *constitute* it ; for animals, whether rational or irrational, would be made susceptible of habit in vain, unless the constitution of external nature had been made to correspond with it ; just as the eye would have been made in vain, had there not existed such a body as light. Now, in what does this correspondence consist ? It consists in that principle whereby nature acts by invariable laws ; for it is evident, that if the laws of nature were variable, those recurrences of perceptions in which habit consists, and on which all experience is built, could not take place ; and this sort of contingency would also destroy all those principles by which prudence and skill operate upon external objects, for the purposes either of common life or of science. The faculty, therefore, by which animals are susceptible of that sort of habit which consists in the association of ideas, may be termed the organ whereby animals perceive the uniform succession of cause and effect, established by the invariable course of nature. It was necessary that this should be an instinct, for the sake of self-preservation, not only to mere animals, but to the human species in infancy. If the noxious effects of fire, and the various modes of mechanical violence, such as falls and blows, were only to be learnt by a process of reasoning, all animals would perish before they could attain to maturity. The great difference of man and mere animals in this respect, seems to be, that the latter only perceive these associations, when the objects themselves are present to their senses, whereas the former, by being endowed with memory, can reflect upon them, and render them subservient to experience : for, with regard to external bodies, what is reason, but the remembrance of objects as they affect each other, and the application of this knowledge to the practice of life, in adjusting means to ends ? The principal difference of one man from
from

from another, in point of understanding, consists in the readiness with which the mind forms these combinations, and the strength with which it can guard against such as are accidental and fanciful, and discriminate these from such as have an archetype in the nature of things; and that mind, of which the conceptions correspond best with the real associations of nature, is possessed of correct judgement and just observation, the most valuable of all mental attainments.

It would lead to disquisitions too long and too intricate, and, in some measure, foreign to this place, to enlarge farther on the various effects of the combination * and succession † of ideas which connect animal with intellectual nature. I shall only remark, that those internal faculties upon which habit and association depend, carry a reference to external nature, exactly analogous to the mutual relation formerly mentioned as subsisting between *stimuli*, whether internal or external, and the moving powers corresponding to them, and between the organs of sense, and the impressions of external bodies which are naturally adapted to them. Muscular motion and sensation have relation to the single properties of matter, as they affect particular fibres and organs, but habit and association are co-relative to that stated connection of cause and effect, established by the general laws of nature. We can thus trace a correspondence between the motions, sensations, and faculties of animals, on one hand, and the properties of matter on the other hand, from the lowest limits of animal and even vegetable nature,

Correspondence between the properties and laws of external nature and the faculties of animals.

* See Theory of the Moods of Verbs, by Dr. Gregory. Phil. Trans. Edin. 1790.

† See a Treatise on Time, by Dr. Watson, jun. F. R. S. Lond. 1785.

into the boundaries of intelligence. The same accordance with the laws of nature is observable in the structure of animals, as in their motions and functions, as may be exemplified by that reference to the powers of gravitation which is evident in the conformation of the limbs and the position of the viscera, as adapted to the natural motions and posture of the body.

It would appear, therefore, that there is a co-ordination or *pre-established harmony*, as it were, between the faculties of animals and the laws of external matter, which is the foundation of all the instinctive habits of animals, as well as the rational conduct of man; and it is impossible sufficiently to admire that sublime contrivance by which the frame of animated beings is thus in all points adapted to the constitution of inanimate nature.

There still remains to be mentioned another circumstance in the animal œconomy, which has been referred to the law of habit. It is the nature of those morbid poisons called specific contagions, such as the infectious matter of the small-pox, not to produce their peculiar effect more than once in life; and this has been imputed to habit, from the similarity of it to what happens with respect to external impressions, the frequency and long continuance of which tend to produce the want of consciousness and sensibility. Upon whatever principle this property of the animal œconomy depends, it is an undoubted fact that these morbid poisons, after exciting a certain degree of disturbance, and a certain series of diseased actions, no longer make any impression on the powers of life, otherwise there could be no such thing as recovery; for at the time in which a person begins to recover from the small-pox, the poison, actually present in the circulating system, is multiplied infinitely beyond

Habits applied to those diseases which affect but once in life.

what it was when it excited the disease. The constitution has therefore, at that time, with respect to this acrimony, acquired an insensibility, or rather want of irritability, and this it preserves ever afterwards. This holds only with regard to those morbid poisons which excite febrile affections, and seems to be a necessary provision of nature to guard against such noxious principles as are generated within the body itself.

IMITATION. The other instinct that remains to be considered, is Imitation. This is an action of which some brutes of no great sagacity are capable, and yet it is the foundation of some of the most important attainments of rational beings, particularly speech, which could not otherwise be acquired, and without which the powers of reason would be extremely limited*. In the early part of human life, imitation seems equally independent of reason and reflection, as in mere animals. It takes place not only without the operation of the will, but in opposition to it; for yawning is an involuntary spasm of the muscles of the jaw, which is frequently excited by a sight of the same action in others; and there is a case recorded in the Philosophical Transactions, by Dr. Garden †, of a man who, in his adult state, and possessed of reason, imitated involuntarily and irre-

* See some ingenious observations on this subject in Dr. Campbell's Philosophy of Rhetoric, Book II. chap. vii.

Speech seems to be to thought what writing is to speech, or rather what arithmetical or algebraical computation is to common language, whether spoken or written; for without speech the operation^f of the mind, particularly that of abstraction, would be extremely limited, nor could there be any of those extensive combinations of thought which constitute a chain of reasoning. It would appear from this, and from the remark in page 39, that all the operations of the human mind are founded on sensation, habit, memory, and speech.

† Phil. Transf. Vol. XII. p. 842.

siftibly whatever gestures he saw in others. We are to account, on the same principle, for that general similarity of external manner and of accent observable in particular societies and nations, and which all men insensibly acquire in a greater or less degree.

The only objects of imitation, are gestures and sounds. The imitation of gestures seems, at first sight, less unaccountable than that of sounds; for it is performed by members which are objects of sight, and would therefore seem more easily transferrable to the corresponding parts of another person; whereas the organs of voice are so hidden and minute, that we can have no knowledge of what parts are put in motion in order to produce sound. But upon farther reflection, there seems little or no difference in this respect; for, independently of anatomy, we know nothing of muscles but by their effects; and there seems no reason why the ear being affected by a sound, should not excite a given motion in the muscles of the larynx and fauces, as well as that a gesture, by having its image impressed on the retina, should excite motions in the legs or arms. Even where imitation, or any other action, is the result of deliberate volition in rational beings, the motion is not performed from a knowledge of their having muscles. They only *will* the effect, without knowing by what means it is performed; for though it may seem obvious that all the motions of an animal are effected by the shortening of the fleshy fibres, this is a fact with which those only are acquainted who have some knowledge of anatomy and physiology, and may be considered as a fundamental and first-rate discovery in the natural history of the living body *.

There

* This discovery cannot be traced to any particular improver of physiology, but seems to have arisen, like many other discoveries in science and the arts, rather

A state of constant tension necessary to the action of muscular fibres.

There still remains to be mentioned, that important property of living muscular fibres, which consists in a perpetual state of tension taking place at all times, in a greater or less degree, independent of any temporary stimulus. When any muscular fibre in a living animal body, whether in a fleshy muscle or a blood-vessel, is divided by incision, there is an immediate retraction of the separated parts; and that this is their natural state, is farther proved by the spontaneous motion which takes place in consequence of the relaxation of an antagonist muscle, as when the mouth is drawn to one side, in consequence of *hemiplegia*. A certain degree of this tension is

from the gradual evolution of knowledge than the efforts of any individual. It has at all times been observed, that exertions of strength produce a swelling and motion in the fleshy parts of the extremities, and the word denoting a muscle in different languages, is taken from the resemblance of the motions under the skin to those of a little nimble animal, such as a mouse or a lizard. A muscle is called in Greek *μῦς*, in Latin *musculus*, or *lacertus*, and that muscle which is so visible near the ham of a quadruped when walking, is, in the common language of some parts of the country, called the *mouse*. It is not ascertained, so far as I know, who first ascribed the motions of animals to the contraction of fleshy fibres. There is no mention made of this in the works of Hippocrates, but it is very clearly stated by Galen; so that the discovery seems to have been made in some intervening period. This property of muscles is so well ascertained in modern times, that wherever we see a muscular substance, we infer synthetically that some corresponding function must belong to it; and we find an irrefragable argument for the circulation of the blood, only from considering the heart as a muscular substance. This subject has not been well understood till modern times, otherwise the circulation would most probably have been discovered sooner; and even since this discovery, we find some physiologists so little acquainted with the nature of muscular power, that they have invented a fanciful theory of the motion of the blood, by a supposed fermentation taking place in the cavity of the heart. We are chiefly indebted to Dr. Glisson, who lived about the middle of the last century, for the first correct ideas of the irritability and contractility of muscular fibres.

necessary

necessary for the performance of the natural motions of the muscles, whether voluntary or involuntary, and the vigor with which the several actions are performed, depends on the fibres possessing a due degree of this constant tone. In order to maintain this tone, there must every where be a counteracting mechanical power, and we perceive accordingly that the great muscles are kept on the stretch by the bones, the heart and vessels by the mass of fluids, and the intestines by the *ingesta*, and their natural contents.

When this tension is either excessive or defective, various irregular and morbid actions are produced. The vascular system is more apt to be affected by various degrees of natural tone than any other part of the body, the reason of which may be, that this very relaxation produces a greater capacity of the vascular system, and the relative quantity of the mass of fluids being thereby diminished, the resiliency and energy of the vessels are not supported even by their former degree of distension. An excess of it may arise either from the too great elasticity of the vessels themselves, or from plethora. The first is indicated by a hard pulse, and that corresponding state of the fluids which occasions in blood, when drawn from a vein and cold, a contraction of the crassamentum, and a fizy crust. Plethora is most apt to arise in constitutions naturally too lax, and which, therefore, do not bear the loss of blood so well as the former.

The excess or defect of this productive of diseases,

A defect of tension in the vessels is produced either by disease, by hæmorrhage, or by natural constitution. In diseases, this want of tension is indicated by general debility and depression of spirits, and by a weakness of the pulse. And as irritability and sensibility are very much affected by tension, a want of it in the vessels chiefly constitutes what is called a nervous habit, such as is most commonly

commonly met with in the female sex ; and there is nothing more apt to induce such a habit than hæmorrhage, which I have known to produce a long train of hysterical symptoms in those who had not formerly been subject to such complaints.

There is a particular constitution incident to both sexes, which is commonly connected with corpulency, and has been called by authors the *temperamentum frigidum*, *phlegmaticum*, and *spongiosum*, and, in common language, a gross and flabby habit. In these there seems to be a deficiency of the natural elasticity of the vessels, and in certain diseases, even of the inflammatory kind, such as the erysipelas, to which they are liable, tonic remedies, such as the Peruvian bark, are found to be the cure, and in diseases of the lungs, chalybeate remedies have been found effectual.

characteristic
of constitu-
tions,

There is, perhaps, no circumstance in which one individual differs more from another, than this natural tension of the muscular fibres ; and it would be more useful, as well as more conformable to nature, to found a discrimination of temperaments upon this, than upon the fanciful theory of humours ; for this difference of constitution not only gives occasion to a variety in natural aspect, but valuable inferences may be deduced from it in the pathology and treatment of diseases.

subject to in-
equality,

Not only the general excess or defect of tension, but the inequality of it, may be considered as a cause of disease. It seems highly probable that those local affections which depend on the congestion of fluids, are owing to the difference of tension in particular parts in relation to the whole system. The whole arteries of the body may be considered as one vessel, the capacity of which is equal to the

the sum total of all the branches of the arterial system, and as every part must be equally distended by the mass of fluids, it follows that if the strength of the vessels of any one part should not be sufficient to support an equilibrium, they must yield more or less to the elastic pressure of the rest of the system.

There is, however, a circumstance of great importance in the animal œconomy, which must tend in some measure to counteract this inequality of tension. When the muscular fibres of any particular part are under a state of more or less tension than the rest of the system, this is communicated by sympathy to every other part of the body. This is particularly observable in the blood vessels and intestines; for a relaxation in any part of these will produce a like affection in every other part of the animal system. With regard to the intestines, it may be mentioned, among many other proofs, that it is common for persons in a state of great weakness to be affected with syncope, and even instantaneous death, in the act of evacuating the bowels. It seems to be from a like cause that a temporary lowness is produced by an abscess being opened. This principle of the animal œconomy has been better illustrated by Dr. Cullen than any other physiologist; and he is of opinion, that great part of the effect of blood-letting in taking off the tension of the vascular system, in cases of inflammation, depends on the depletion of the vessels of the part from whence the blood is taken, for the proportion of the quantity drawn to the whole mass is very small; and it may also be urged in favour of this opinion, that the more suddenly the evacuation is made, the more effectual is its operation in removing the inflammatory disposition, inasmuch as the local depletion will be greater, the less time is allowed for the balance of the system to replace it.

and much influenced by sympathy.

WHAT

Muscular motion considered mechanically.

WHAT has been hitherto said of Muscular Motion, has had relation to it as a property peculiar to animal matter and animal life. What I have farther to add on this subject, will relate to the muscles merely as mechanical powers. As they constitute the strength of animals, it may be proper to consider the relation of their force to their bulk, and the relation of the bulk and strength of the body to the density and cohesion of its own materials, and to the bulk, density, and cohesion of the external inanimate bodies with which it is conversant.

It has been demonstrated by Galileo*, that in similar unequal bodies of a cylindrical or prismatic shape, such as the limbs of animals nearly are, the ratio of their efforts to break by their own weight, is in the quadruplicate ratio of their lengths, but that the resistance they make to the same force is only in the triplicate ratio of their lengths. It follows from this, that in order to endow the limbs of animals with the same relative force, it is not only necessary that the bones should possess an increased proportion of thickness, in order to give an adequate increase of what may be called the dead strength, but a similar increase of living strength will be necessary, by a suitable addition of muscular power, in order to keep pace with the increased size of the bones. Now we observe, in fact, that in the large-sized animals, such as the bull and the elephant, the thickness both of their bones and muscles bears a greater proportion to the length of their limbs, than in the smaller animals, and they are therefore of a less elegant form. But Nature has not carried this so far, as to compensate for the disadvantage

* Vid. Opere di Galileo. Discorsi e dimostrazione mathematiche.

arising from the increase of size; for the greater animals have not the same proportional strength, in relation to their bulk, that the smaller animals have. It has been computed* that a flea can draw from seventy to eighty times its own weight, whereas a horse cannot with ease draw more than three times his own weight. This disproportion between strength and size is very observable in different individuals of the human species, when compared to each other; for tall men are not muscular, even in the simple proportion of their stature. The difference in the shape and size of different men may be considered as an accidental variety, or *lufus naturæ*, owing, probably, to his artificial mode of life, and for which Nature has made no special provision.

We are led, however, from a view of the same mechanical principles, to perceive the wisdom of Nature in assigning certain general limits to the stature of the human body. Had man been made much larger, he would have been unwieldy, and subject to accidents in his motions, in consequence of the *momentum* of the parts increasing in a higher ratio than their power of resistance. It may be answered, that the parts might have been made proportionally more hard and tenacious. But there are other circumstances in the animal œconomy which would have been a bar to this; for had the bones been harder, they would not have been calculated for the common duration of life, the effect of which being to increase their hardness and dryness, they must be endowed originally with a certain degree of softness and succulence. And with regard to muscles, a degree of hardness, much greater than they naturally possess, would have been incompatible with their contractility.

The strength and stature of the body properly adapted to external nature.

* Vid. Haller Elementa Physiologiæ. Cap. IX. Sect. II.

Another inconvenience of the greater stature of man would be, that he would require larger habitations, more food and clothing, while he would have less relative strength to provide for these wants. On the other hand, had man been of a stature much less than what he enjoys by nature, he would not have possessed sufficient power over external objects, to act up to those superior faculties of mind with which he is endowed. If nature had conferred on man only one half of his actual stature and strength, with the same powers of reason, we may venture to affirm that he would not have carried his dominion over nature to the same extent. As he is now constituted, his force being commensurate with external nature, he has been able, either by force or artifice, to assert his sovereignty over the woods and fields, by mastering the strongest and fiercest wild beasts ; he has been able to change the whole face of nature on the surface of the earth, by works of industry, and monuments of art ; he has been able to fell trees, to build ships, and to circumnavigate the planet he inhabits. It is rather a triumph of his reason than of his corporeal strength, to say, in the language of a modern poet *, that he can

“ Measure earth, weigh air, and state the tides ;”

or, according to the sublime idea of an ancient philosopher †, that he could turn the earth from its orbit, could he find footing on another earth, from whence to exert the powers of mechanism ; but such knowledge and such conceptions could never have been attained but by a being of a certain degree of bodily strength and stature.

From what has been said, it may safely be inferred, that as the external bodies with which we are conversant possess given degrees

* Pope.

† Archimedes.

of cohesion, bulk, and density, which require corresponding powers to act upon them; so the human body, at its mean stature, is best adapted for producing those changes upon matter, which are necessary for self-preservation, and the various accommodations of life. And an argument may be drawn from hence against the tenets of those speculative philosophers, who hold that the size and strength of man were much greater in remote antiquity than in modern times. It is evident, from what has been said, that if the bulk of the human body were much greater than it is, it would be both useless and inconvenient, and would not preserve that harmony with the rest of nature, which is so agreeable to the analogy of her other works.

I shall conclude this Lecture with some remarks on the muscles, considered as mechanical powers acting upon levers.

The muscles considered as mechanical powers acting upon levers.

The first remark to be made upon this, is so obvious, that it has hardly escaped the notice of any modern physiologist, and seems at first sight to militate against that wisdom of nature which is so conspicuous in other respects. What I mean is, the great waste of mechanical power which is incurred by the manner in which the muscles are inserted into the bones. This disadvantageous action of muscles is chiefly owing to two circumstances. One of these is their insertion, in almost every instance in which they are connected with bones, into a part which is much nearer the fulcrum than the resistance. Thus the two muscles of the arm, called the *biceps* and *brachialis internus*, in order to support in the hand a weight of one pound with the fore arm at right angles to the *humerus*, must exert a power equal to ten pounds. The other circumstance giving rise to a waste of power, is the great obliquity with which they are inserted into

Their disadvantageous action, i. e. From the manner of their insertion into the bones.

the bones upon which they are intended to act, so that the greater part of the force is expended in pressing one bone against another at the articulation, and only a small portion of it in making the flexures and extensions; so as to produce the desired effect at the extremity.

This compensated by preserving the shape of the parts,

But these disadvantages are compensated by certain conveniences, and if nature has endowed the muscles with sufficient power for the purposes of life, after making allowance for the waste of force, there can be no reason to find fault with her management. One of the principal advantages arising from this distribution of the muscles, is the preservation of the shape of the members; for unless the muscles and tendons had been pretty nearly in the direction of the bones, they must have passed like bow-strings from one bone to another, in making the flexures of the joints.

and in actions of percussion,

In estimating the waste of force, in consequence of the mechanical disadvantages before mentioned, we are to distinguish between those actions which consist in pressure, and those which consist in percussion; for as the *momentum* of the latter depends on velocity, it is evident that there is a great advantage from the insertion of the tendon being near the centre of motion, as greater velocity, with less expence of contraction, will be thereby imparted to the extremity. The muscles, for instance, which are attached to the *olecranon*, in performing those actions with the hand which require rubbing, act with a disadvantage, exactly in proportion to the inequality of the distance from their insertion to the joint of the elbow, and that from the same joint to the hand. This is an act of pressure. But in the case of percussion, as in the action of using a hammer,

hammer, there is an evident advantage resulting from the velocity communicated to the extremity ; for in order to have produced the same velocity, with the insertion at a greater distance from the centre of motion, a greater range of contraction would have been necessary. The saving of contraction, therefore, may be reckoned another principal advantage in the attachment of muscles near to the centre of motion. As this is a point which I think has not been attended to, in explaining the mechanism of the muscles, I shall conclude with some remarks upon it.

by saving contraction.

As the muscles of voluntary motion are subject to fatigue, every circumstance that can tend to diminish this, will be favourable to the purposes of nature. Fatigue depends upon the force, frequency, duration, and extent of the contraction of muscular fibres. It is this last which is meant here to be illustrated. If any one will take the trouble of comparing the fatigue of the *biceps* muscle, in bearing a weight in the hand, with the elbow joint bent to a right angle, with that of bearing the same weight for the same length of time, with the joint at an acute angle, he will be sensible how much the degree of fatigue depends on the extent of contraction, and by attending to the relative situation of muscular fibres, it will appear that nature, in distributing the fibres of muscles obliquely, has had it in view not only to increase their number, but to save contraction.

2. Disadvantage from the obliquity of muscles to each other.

In surveying the actions of all the various muscles, it appears, not only from the co-operation of different muscles, but from the position of the fibres in the same muscle, that there is hardly an action to be met with that can be called direct. In some instances, two muscles, or sets of muscles, are made to co-operate, so that
the

Oblique action universal in muscles, in relation to each other.

the motion effected by them shall be in the diagonal of their direction. This is the case of the oblique muscles of the abdomen in some of their actions, and the intercostal muscles in all their actions. Sometimes, different portions of the same muscle produce in like manner an intermediate and combined effect, as in the instance of the *cucullaris*, one part of which being attached to the *vertebræ* of the neck, and another to those of the lower part of the back, their joint effect is to draw the *scapula* towards the spine. And in all the long muscles, however simple their origin and insertion may be, there is an internal obliquity of their fibres, in regard to each other, as described by the late Dr. Hunter; for these do not run from end to end, but there are parts of the tendon running into the belly of the muscle, so as to divide it into penniform and rhomboidal portions. This distribution of the fibres takes off from their length; but as it takes place in those cases where the origin and insertion are at a considerable distance, this can be afforded; and this, as well as the waste of power, in consequence of oblique action, is more than compensated by the increased strength, from the fibres being multiplied; for, in consequence of this structure, there is an extent of tendon afforded sufficient for the insertion of a greater quantity of fleshy fibres.

and in the fibres of the same muscle.

Compensated, i. by multiplying the number of fibres.

This illustrated in the structure of fish.

This principle in the mechanism of muscular action, is well illustrated by considering the motions of fish. The muscles of most fish consist of regular series of oblique short fibres, forming those *strata* which every one must have observed in their muscular substance. Their motions are more simple and limited than those of land animals, but much more vigorous; for a fish in the sea has to make its way through a medium about a thousand times more dense than air,

air, and with more rapidity. Nature, therefore, instead of giving them muscles whose fibres would run straight from one end of their body to the other, has multiplied their numbers, by distributing them into short and oblique portions. If one was called upon to name instances of the greatest muscular efforts, it is in fish that these are to be found. I have seen the sword of a sword-fish sticking in a plank, which it had penetrated from side to side; and when it is considered that the animal was then moving through so dense a medium, and in the same direction with the ship, we must form a high conception of its muscular power.

An advantage the reverse of what has been stated, arises from the oblique direction of the intercostal muscles, the fibres of which are thereby lengthened; for in parts so near each other as the ribs, there would have been a great inconvenience in their passing directly from one to another. Besides, in consequence of their oblique direction, the origin in the superior rib is placed nearer to the centre of motion than the insertion in the inferior rib, the effect of which is, that all the ribs are elevated, whereby the cavity of the thorax is enlarged, which is the view of nature.

But the advantage or rather compensation of obliquity, which I mean particularly here to demonstrate, is, that the same effect is produced with a less proportional decurtation of fibres, than if the same motion had been performed by a direct power. Borelli has estimated geometrically the loss of power from oblique action, but seems to have overlooked this compensation of it, which is not inconsiderable, when we reflect that there is thereby a saving of contraction, and consequently of fatigue. This can be rendered an object of geometrical

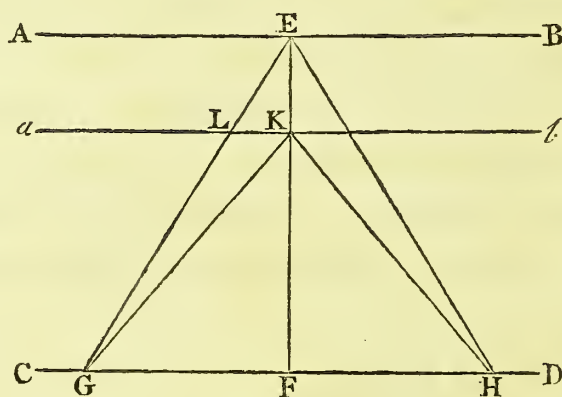
2. By saving contraction.

metrical proof, and I here subjoin a demonstration of it, which I made out, when engaged in the study of anatomy, eighteen years ago.

This demonstrated by a theorem.

Let the line AB , in the annexed diagram, represent a moveable bone, and the line CD a fixed bone parallel to it. Let FE , perpendicular to these lines, represent a muscle acting in its own direction, and the lines GE HE represent two muscles acting obliquely, and producing, by a diagonal action, the same effect as the other. If the bone AB be brought to the situation ab , by the action of the muscle FE , the muscle will then be in the situation FK . If the bone is brought into the same situation by the action of the muscles GE , HE , these muscles will then be in the situation GK , HK .

The proposition to be demonstrated is, that the line GK bears a greater proportion to the line GE , than the line FK does to line FE ; for FK is to FE as GL is to GE . (Euc. Elem. B. vi. Prop. 2.) and the angle ELK , being less than a right angle, the angle GLK , which is adjacent to it, must be greater than a right angle; and the angle GKL , being in the same triangle with GLK , must be less than a right angle. The line GK , therefore, which subtends the greater angle, is greater than the line GL , subtending the lesser, and therefore bears a greater proportion to GE . But the line GL is to GE , as FK is to FE ; and therefore GK bears



bears a greater proportion to GE , than FK does to FE ; that is, the fibres of the muscles acting obliquely, suffer a less proportional decurtation than those of the muscle acting directly.

It is farther obvious, that the more oblique the action becomes, the greater saving there will be of contraction; for in moving the line ab towards CD , the line FK diminishes in a swifter ratio than the line GK , and when the former has vanished, the latter is in the situation GF .

I have thus endeavoured to sketch some of the most important particulars in the natural motions of living animals, a subject which affords one of the finest and most fertile fields for contemplating the wisdom with which Nature adapts her means to her ends; and which has been justly considered as carrying the most irresistible evidence of the existence of an intelligent cause. The subject is so far from being exhausted, that I am convinced there are circumstances in the relative distribution and correspondence of organs, depending on muscular motion, so profound and exquisite, as far to exceed the utmost reach of human thought to comprehend, or of human ingenuity to detect: and here, as in every other part of the frame of the universe, the most elevated conceptions which the most ^{ex} ^{ed} rapturous ~~our~~ imagination can form of the beauty and magnificence of Nature, will fall far short of the real sublimity of her works. Conclusion.

THE END.

